Engineering Properties of Fly Ash and Rice Husk Ash-Based Geopolymer Concrete

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1 Introduction

Concrete is second most widely used construction material in the world after water [1]. Cement is the chief binding material in concrete. Popularity of cement as binding material is due to its ease in availability and utility, moldability into any shape and size and that it can be easily made by even an unskilled person. But at the same time, production of cement is highly energy-consuming process as it requires lot of energy to produce clinker from raw materials and grinding of clinker to produce cement. Besides this, one ton of cement approximately produces one ton of carbon dioxide gas in atmosphere and also releases carbon monoxide and nitrous gas in atmosphere [2]. Progress of any country is measured by amount of industrial growth and energy it consumes. In the developing country like India, power is mostly produced by thermal power plant, which creates huge amount of fly ash as a residue. Effective utilization of fly ash is also need of an hour. Geopolymer concrete is one of the sustainable concrete as it uses industrial waste rich in silica and alumina as its source material. The concrete is activated by alkaline activators in the form of sodium or potassium-based hydroxide or silicates or its combination [3]. As geopolymer concrete used mostly industrial waste, it is sustainable and eco-friendly. Geopolymer is a term coined by Prof. Davidovits [4]. In geopolymerization, a long chain of reaction takes place of source material rich in silica and alumina activated with sodium or potassium-based activators into a long chain of molecules [4].

India's power production is 70% dependent on coal-based thermal power plant. Huge amount of fly ash is generated and it is commitment of government of India to utilize 100% fly ash produced from thermal power plant. At present, unutilized fly ash is dumped in landfill causing land, water, and air pollution and affecting health of citizen. India being an agricultural country produces huge volume of rice. Rice

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S. Biswas et al. (eds.), *Advances in Sustainable Construction Materials*, Lecture Notes in Civil Engineering 124, https://doi.org/10.1007/978-981-33-4590-4_69

husk ash (RHA) produced during cleaning of rice is disposed as landfill. As RHA is lighter, it has lot of disposal problems for rice mills and needs effective technology for its reuse. This husk contains 75% of organic volatile matter and has high amount of silica. The amorphous silica contained in RHA can react with cementitious binders to perform pozzolanic activity [5]. As reactive silica in RHA is lesser, hence it is to be mixed with fly ash in geopolymer concrete production.

2 Research Significance

Aim of the present investigation was to have an effective utilization of fly ash and RHA as source material in geopolymer concrete. As lot of RHA is produced in India, use of rice husk ash as source material will lead to reduction of this material as landfill. The paper discusses parametric study of factors responsible for strength of fly ash and rice husk ash-based geopolymer concrete (FRGC). It also attempts to find various mechanical properties of the designed concrete such as compressive strength, split tensile strength, and flexural strength. A detail microstructure study reveals structure of fly ash and rice husk ash used in the investigation.

3 Literature Review

Micronized biomass of rice husk ash was used in combination with slag by Ambily et al. [6]. Using sodium-based activators and varying rice husk ash from 0 to 30%, tests were done on density and slump. It was observed that for higher compressive strength more than 10% of micronized rice husk ash had to be used. Kusbiantoro et al. [7] used combination of fly ash and microwave incinerated rice husk ash-based geopolymer concrete. They observed that under temperature curing due to incorporation of RHA the strength increased as refinement of pore structure occurred and higher compressive and bond strength was achieved. Bernal et al. [8] studied mechanical and structural changes induced by high temperature exposure of paste made from rice husk ash and silica fume combined with slag. They found that paste samples had strength more than 50 MPa and retained the same strength up to 600 °C.

4 Experimental Program

Materials used in the investigation were fly ash and RHA as source materials, combination of sodium hydroxide and sodium silicate, coarse aggregate, fine aggregate, and admixture.

Table 1 Properties of fly ash

Particulars	Unit	Test results	Fly ash specification (IS:3812) [9]
Color	–	Light gray	–
Specific surface area	m^2/kg	416.36	320 min
Loss of ignition	%	1.05	5.0 max
$SiO_2 + Al_2O_3 + Fe_2O_3$	%	93.02	70 min
SiO_2	%	61.40	35 min
CaO	%	5	7.0 max
Reactive silica	%	34.36	20 min
Total chlorides	%	0.03	0.05 max
Pozzolanic activity index	%	82.44	80 min

Table 2 Properties of rice husk ash

Characteristics	Test results
Color	Dim gray
Specific surface area (m^2/kg)	293
Loss on ignition (%)	4.51
SiO_2 (%)	89.84
$Al_2O_3 + Fe_2O_3$ (%)	2.45
Specific gravity	2.23

4.1 Material Specification

4.1.1 Class F Fly Ash

Class F fly ash used in the investigation was procured from Ukai Thermal Power Plant in Gujarat. Table 1 shows physical and chemical properties of fly ash used in the investigation.

4.1.2 Rice Husk Ash

Rice husk ash was procured from local rice cleaning mill near Ahmedabad. Properties are shown in Table 2.

4.1.3 Alkaline Solutions

Sodium hydroxide (NaOH) was obtained from local supplier and had 98% purity. It was in flakes form and was dissolved in tap water depending upon required molarity. Figure 1 shows the NaOH flakes used in investigation and it did not have any chloride

Fig. 1 NaOH flakes used in investigation

Table 3 Properties of sodium silicate

Na_2O	15.5%
SiO_2	35.4%
SiO_2/Na_2O	2.23
Specific gravity	1.58

content. Properties of sodium silicate (Na_2SiO_3) which was in liquid form are shown in Table 3.

4.1.4 Aggregates

Combination of 20 and 10 mm coarse aggregates of 20 and 10 mm were used which were locally available fine aggregates was used. Coarse aggregate had specific gravity of 2.7 while river sand of Zone II constituted fine aggregates.

4.1.5 Super Plasticizer

Polycarboxylic ether-based super plasticizer was used for increasing the workability of geopolymer concrete.

4.2 Preparation of Concrete

Geopolymer concrete with fly ash and rice husk ash (FRGC) was designed for M25 grade of concrete. Density of FRGC was assumed to be 2400 kg/m^3 which is same as ordinary cement concrete. Of the total volume, it was assumed that 75% will be occupied by aggregates, i.e., combination of coarse and fine aggregates. Alkaline activators were sodium based. As NaOH generates lot of heat on mixing with water, hence it was dissolved a day before casting and Na_2SiO_3 was mixed into the solution some time before the casting to form alkaline solution. It is necessary to carry out parametric study to evaluate factors affecting the compressive strength. Six parameters were considered for evaluation and variation was done in one parameter keeping other parameters constant. Variation done was in amount of source material, molarity of NaOH, amount of alkaline solution, varying the alkaline solution to cementitious material ratio, amount of extra water and amount of admixture. Like the ordinary concrete, initial dry mixing of source material was done and after that aggregates were added and mixed for 4–5 min. After this, alkaline activators were added and thoroughly mixed and then addition of extra water and admixture was done. The specimens were kept at 60 °C after 1 day rest period. Oven curing was done for 24 h, and then specimens were kept in open atmosphere before testing.

5 Parametric Study

5.1 Effect of Amount of Source Materials

RHA is produced mainly be cooling suddenly and unevenly and hence reactivity of RHA is very less. RHA is very coarse in nature and very porous and hence as the amount of rice husk ash increased in the concrete mixture there was drastic decrease in compressive strength. RHA used was not grinded and used as in available condition. Grinding would increase cost of production and hence would not be viable solution. RHA was restricted to 5% of fly ash as larger percentage did not give desired compressive strength.

5.2 Effect of Change in Molarity of Sodium Hydroxide

Amount of NaOH is very important parameter for design of geopolymer concrete. Amount of NaOH indicates more alkaline solution is available for reaction. However, it is also found that with increase in molarity, excessive amount of Na++ ions decreases the strength of geopolymer concrete. Figure 2 shows the increase in compressive strength of FRGC when alkaline solution ratio (AR) is 0.35. It can be observed that when FRGC has 12 M at AR of 2.5 highest compressive strength of 29.6 MPa is achieved. At AR of 2.5 at 14 M compressive strength decreases to 27.6 MPa. Therefore, 12 M at 2.5 AR ratio can be chosen.

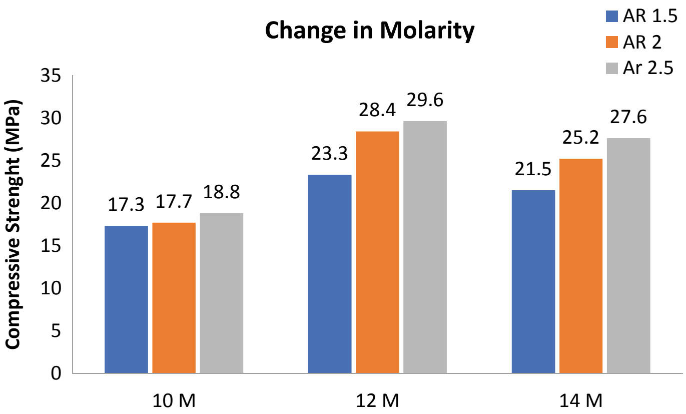

Fig. 2 Variation in compressive strength due to molarity change

5.3 *Effect of Change in Alkaline Solution Ratio*

Compressive strength of geopolymer concrete with combination of fly ash and rice husk ash is governed by ratio of Na_2SiO_3 to NaOH used in the concrete mixture. This ratio is also called as alkaline solution ratio. Higher AR ratio indicates more amount of sodium silicate in the concrete, which will have more amount of reactive silicates for geopolymerization process. This will enable longer chain reaction leading to increase in compressive strength of mixture. Ratio of alkaline solution to cementitious material is kept at 0.3. Figure 3 shows that at 10 M solution with increase in AR ratio from 1.5 to 2.5, compressive strength increases from 9.3 to 10.8 MPa. Similarly, at 14 M,

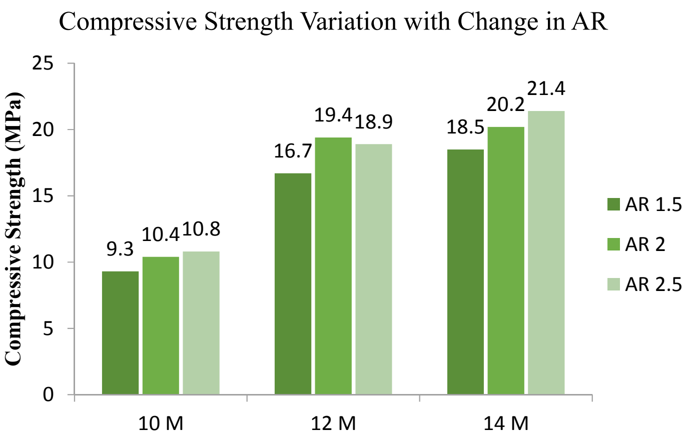

Fig. 3 Change in compressive strength with variation in molarity and AR

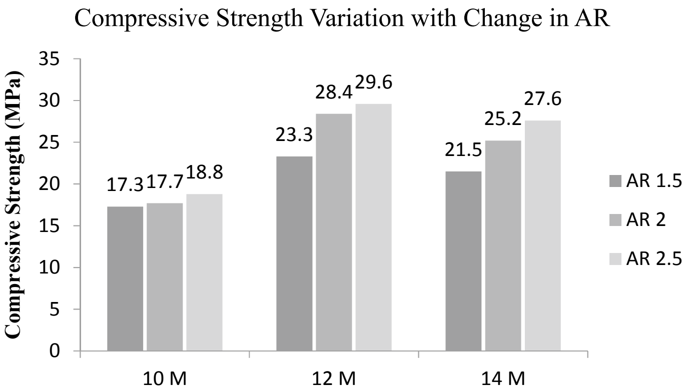

Fig. 4 Change in compressive strength with variation in molarity and AR

when AR ratio increases from 1.5 to 2.5, compressive strength increases from 18.5 to 21.4 MPa.

When alkaline solution to cementitious material is increased to 0.35, then as observed in Fig. 4, with increase in AR ratio from 1.5 to 2.5, at 10 M compressive strength increases from 17.3 to 18.8 MPa while 14 M NaOH is used and AR increases from 1.5 to 2.5, compressive strength increases from 21.5 to 27.6 MPa. Thus due to more availability of silicate ions for reaction with source material, compressive strength increases.

5.4 Effect of Change in Alkaline Solution to Cementitious Material Ratio

Alkaline solution is a combination of amount of NaOH and Na_2SiO_3 in a mixture. Increase in amount of alkaline solution indicates more amount of reactive material available for geopolymerization reaction. As observed in Fig. 5, at 10 M when alkaline ratio increases from 0.3 to 0.4, for AR 1.5, compressive strength increases from 9.3 to 17.3 MPa while for AR ratio of 2.5, compressive strength increases from 10.8 to 18.8 MPa.

As shown in Fig. 6, at 12 M the compressive strength changes from 16.7 to 23.3 MPa with change in alkaline solution to cementitious material from 0.3 to 0.4 at AR ratio of 1.5, while increase in compressive strength takes place from 18.9 to 29.6 MPa, when AR ratio is 2.5 and alkaline solution to cementitious material ratio changes from 0.3 to 0.4. In Fig. 7, when change in AR ratio is 1.5 with increase in alkaline solution to cementitious material from 0.3 to 0.4, compressive strength changes from 18.5 to 21.5 MPa. Similarly, with change for 14 M at 2.5 AR ratio, compressive strength changes from 21.4 to 27.6 MPa.

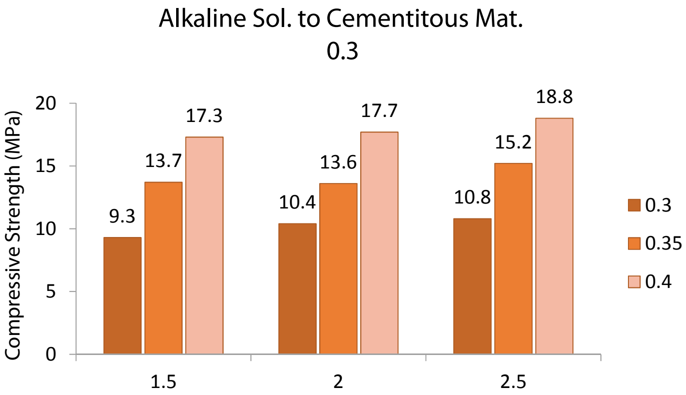

Fig. 5 Change in compressive strength with variation in AR to cementitious material ratio at 10 M

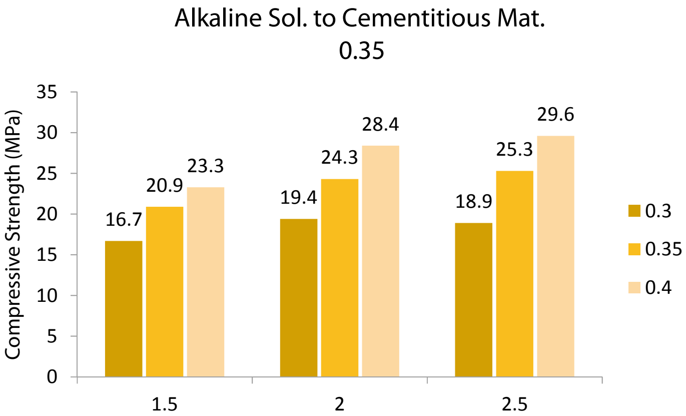

Fig. 6 Effect of alkaline solution to cementitious mat. Ratio on compressive strength (12 M)

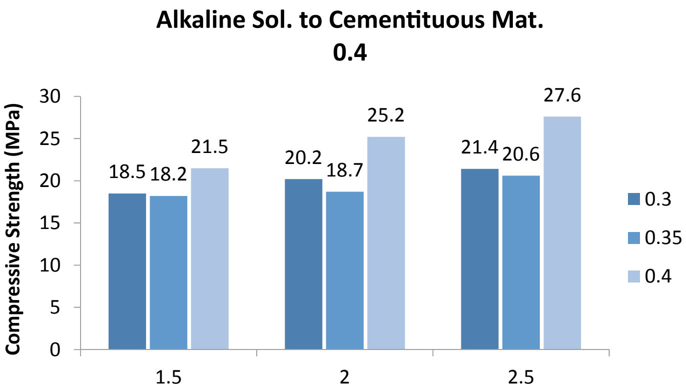

Fig. 7 Effect of alkaline sol./cementitious mat. ratio on compressive strength at 14 M

5.5 Effect of Admixture Dosage

With increase in admixture dosage from 1.5 to 2%, there is small increase in compressive strength 28.6 to 29.4 MPa, but the cost of FRGC also increases and hence dosage is restricted to 1.5%.

5.6 Effect of Extra Water

Increase in extra water for 10–15% increases workability of FRGC, but also reduces compressive strength of concrete, and hence, extra water is restricted up to 10%.

6 Mixture Proportions and Mechanical Properties of FRGC

The final mixture design of FRGC is given in Table 4.

6.1 Compressive Strength

Evaluation of compressive strength was done on 150 mm cube on 2000 kN hydraulic testing machine in accordance with procedure in IS 516 [10]. Compressive strength was evaluated as load per unit cross-sectional area. Compressive strength of FRGC was found to be 30.5 MPa.

Table 4 Mix proportion of FRGC

Fly ash	407.2 kg/m^3
Rice husk ash	21.4 kg/m^3
Coarse aggregate	
20 mm	702 kg/m^3
10 mm	468 kg/m^3
Fine aggregate	630 kg/m^3
Sodium hydroxide	57.2 kg/m^3
Sodium silicate	114.29 kg/m^3
Admixture	8.6 kg/m^3
Water	42.85 kg/m^3

6.2 Split Tensile Strength

Split tensile strength was evaluated on 150 mm diameter and 300 mm height cylinder according to IS 5816[11] provision on 2000 kN universal testing machine. The split tensile strength was found to be 3.37 MPa.

6.3 Flexural Strength

Evaluation of flexural strength was done on 100 mm × 100 mm ×500 mm beams cast and average of three beams was taken as flexural strength of FRGC. The flexural strength was found to be 4.07 MPa.

7 Microstructural Studies

Rice husk ash is shown in Fig. 8 with magnification of 85X. It shows that rice ash husk is extremely coarse in nature and shows lot of undulations and is very rough. This can be seen in results also, as when dosage of rice husk increases, workability and compressive strength decreases due to large amount of absorption of water by rice husk ash particles. EDAX image shows occurrence of large amount of silica in the rice husk ash but due to amorphous nature it is not reacting and does not contribute much significantly in strength mechanism of FRGC.

Fly ash particles are very spherical and have combination of small and large particles of fly ash. Smaller particles will react fast and give early strength to FRGC. Figure 9 shows SEM image and EDAX micrograph of fly ash. In fly ash along with silica, alumina ions are also found which give strength to FRGC.

SEM image of FRGC is shown in Fig. 10. It shows that some particles of fly ash are yet to react and also rice husk ash particles are seen. However, due to denseness of mixture compressive strength is achieved in the FRGC as reflected by various mechanical properties like compressive and flexural strength.

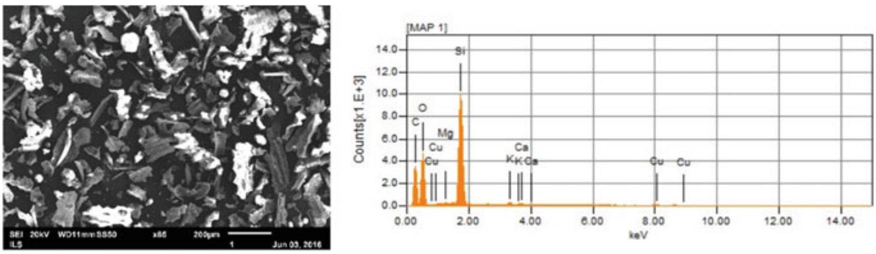

Fig. 8 SEM image of rice husk ash particles and EDAX micrograph

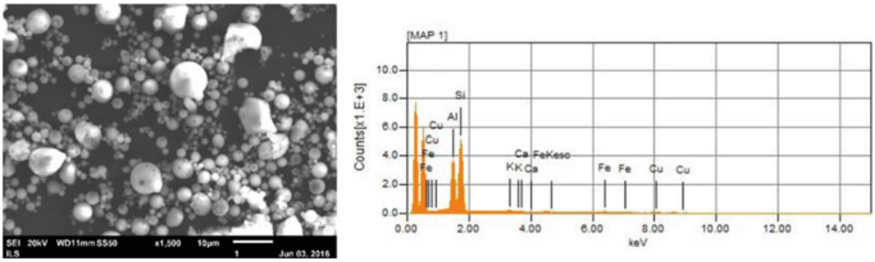

Fig. 9 SEM image of fly ash particles and EDAX micrograph

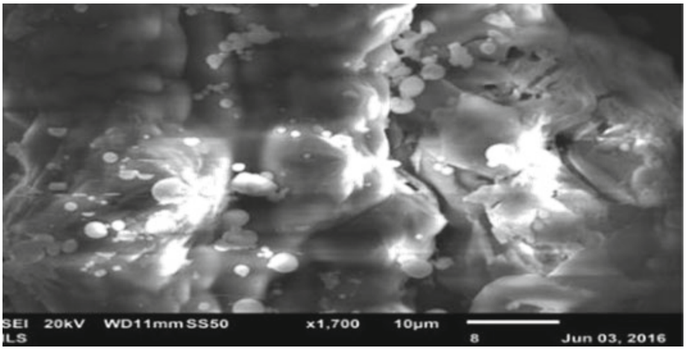

Fig. 10 SEM image of fly ash and rice husk ash geopolymer concrete

8 Conclusion

Following conclusions can be made based on the investigation:

- Rice husk ash is coarse in nature as seen in SEM images and is highly porous and therefore larger amount will lead to decrease in compressive strength. Therefore, only 5% can be used in FRGC of M 25 grade.
- Increase in molarity up to 12 M increases compressive strength but beyond that there is decrease in compressive strength of FRGC.
- Increase in alkaline solution leads to increase in compressive strength of FRGC.
- Increase in alkaline solution to cementitious material leads to increase in compressive strength. Judicious choice of admixture and dosage of extra water should be made.
- M 25 grade FRGC had good mechanical properties in compression, split tension, and flexural strength.

Acknowledgements The author is grateful to Nirma University, for funding the present investigation under Minor Research Project.

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